Diesel — What the Future Holds

Michael D. Jackson

Presented at
22nd National NGV Conference & Exhibition

Panel Discussion on

Will the Real "Clean Fuel" Please Stand Up: Sorting Fact From Fiction About Heavy-Duty Engines

September 19-21, 2004
Henry B. Gonzalez Convention Center
San Antonio, Texas

TIAX LLC
1601 S. De Anza Blvd., Suite 100
Cupertino, California 95014-5363

Reference: E3000.03 7659

1. Background and Issues
2. Heavy-Duty On Road Standards
3. 2007-2010 Heavy-Duty Diesel Engines
4. Summary Comments

1. Background and Issues
2. Heavy-Duty On Road Standards
3. 2007-2010 Heavy-Duty Diesel Engines
4. Summary Comments

Emissions that result in largest societal damages are PM and NOx

Direct Particulate Emissions
PM<2.5 μ

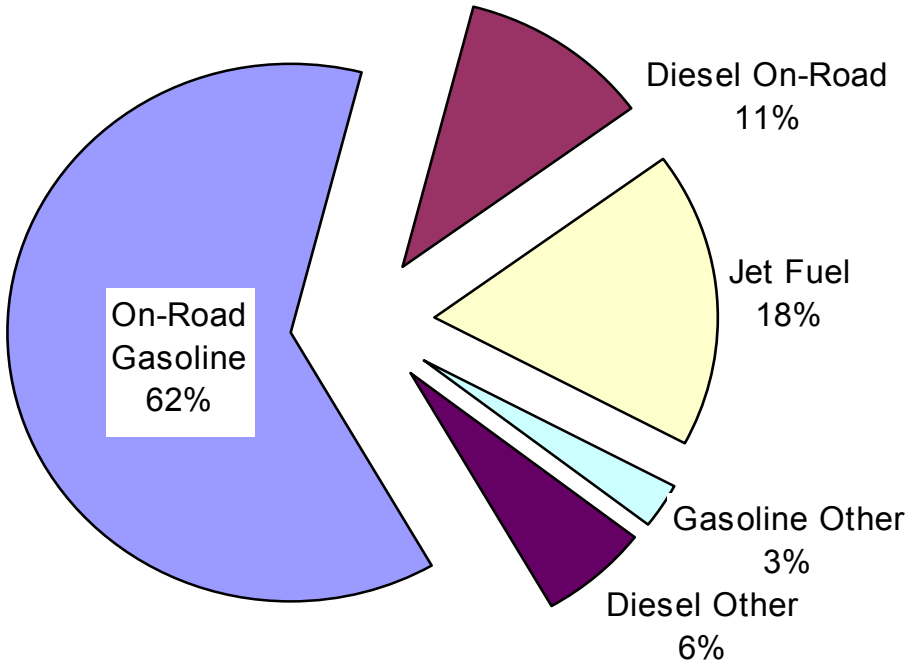
Oxides of Nitrogen
NOx

Ozone O_3
Secondary Particulate

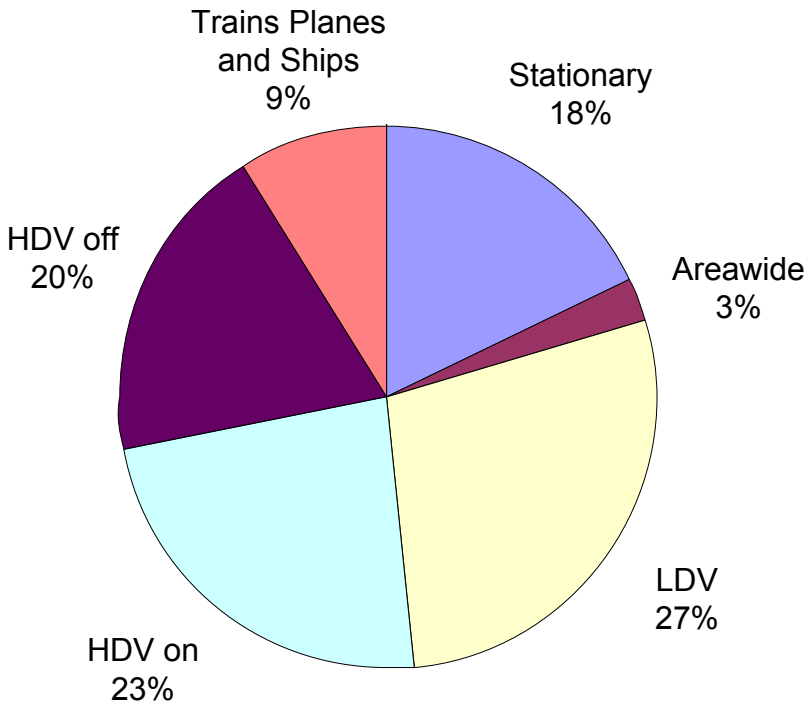
Hydrocarbons
HC
Toxics

Carbon Monoxide
CO

Diesel Emissions Much Greater than Gasoline Emissions

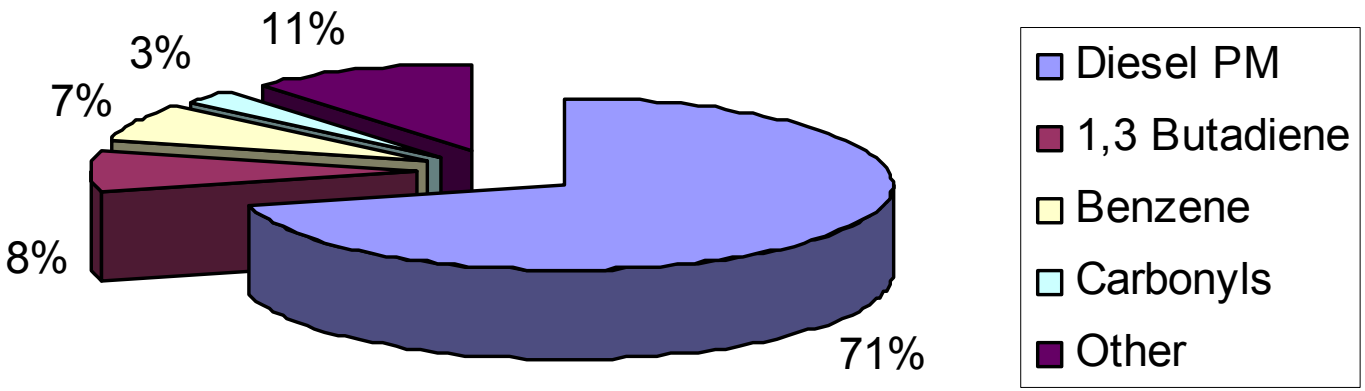


Fuel Consumed



NOx Emissions

Diesel Particulate from mobile sources dominate the cancer risk in the South Coast Air Basin

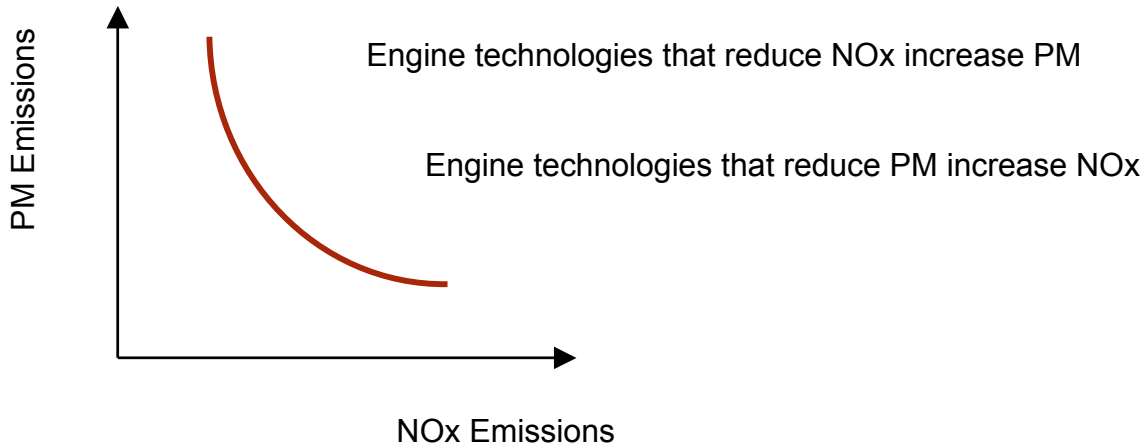


Basinwide Cancer Risks about 1400 in one million

1. Background and Issues
2. **Heavy-Duty On Road Standards**
3. 2007-2010 Heavy-Duty Diesel Engines
4. Summary Comments

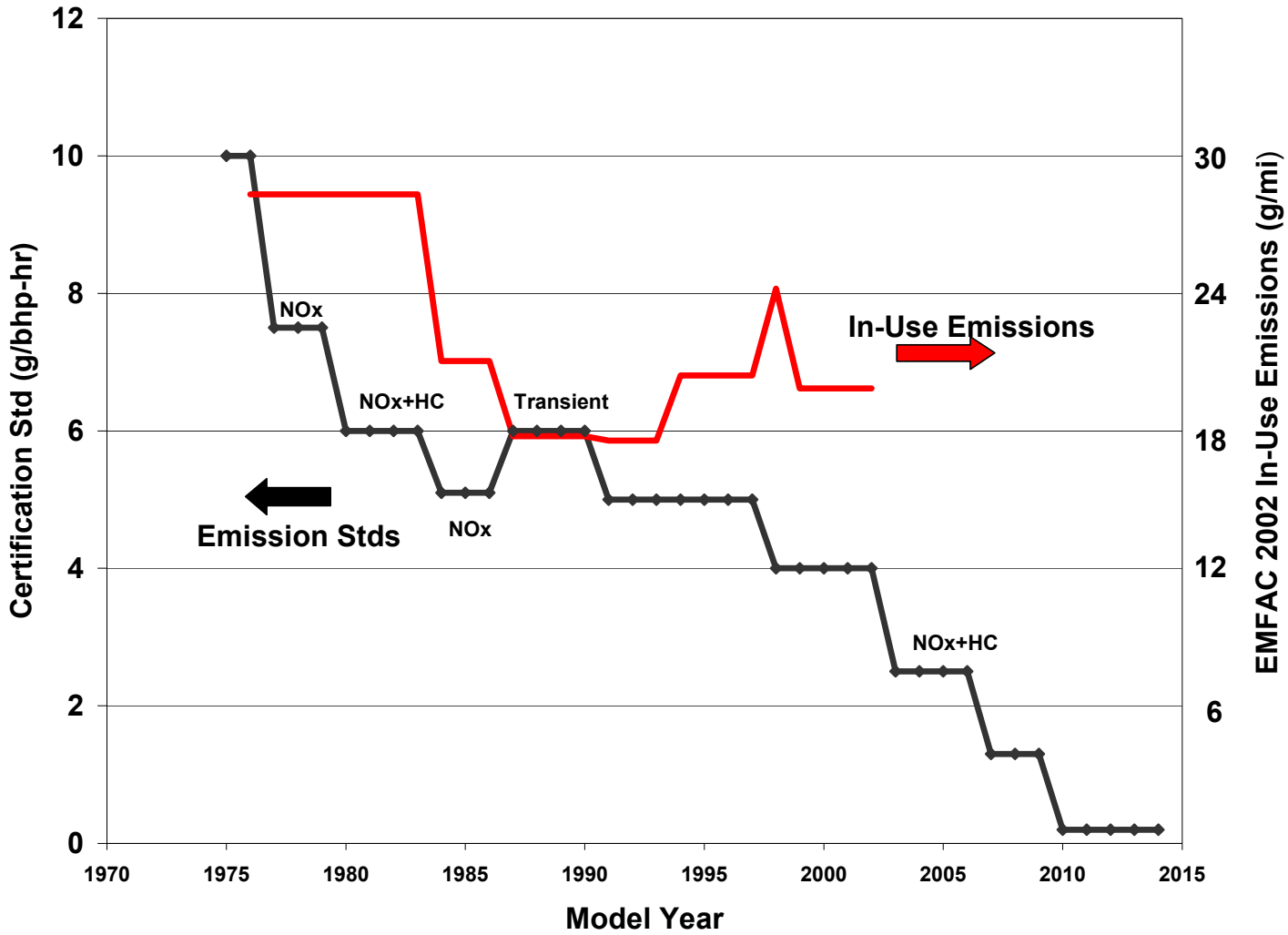
Diesel Engines emit higher emissions of NOx and PM than other engines

- NOx–PM tradeoff for Diesel Engines

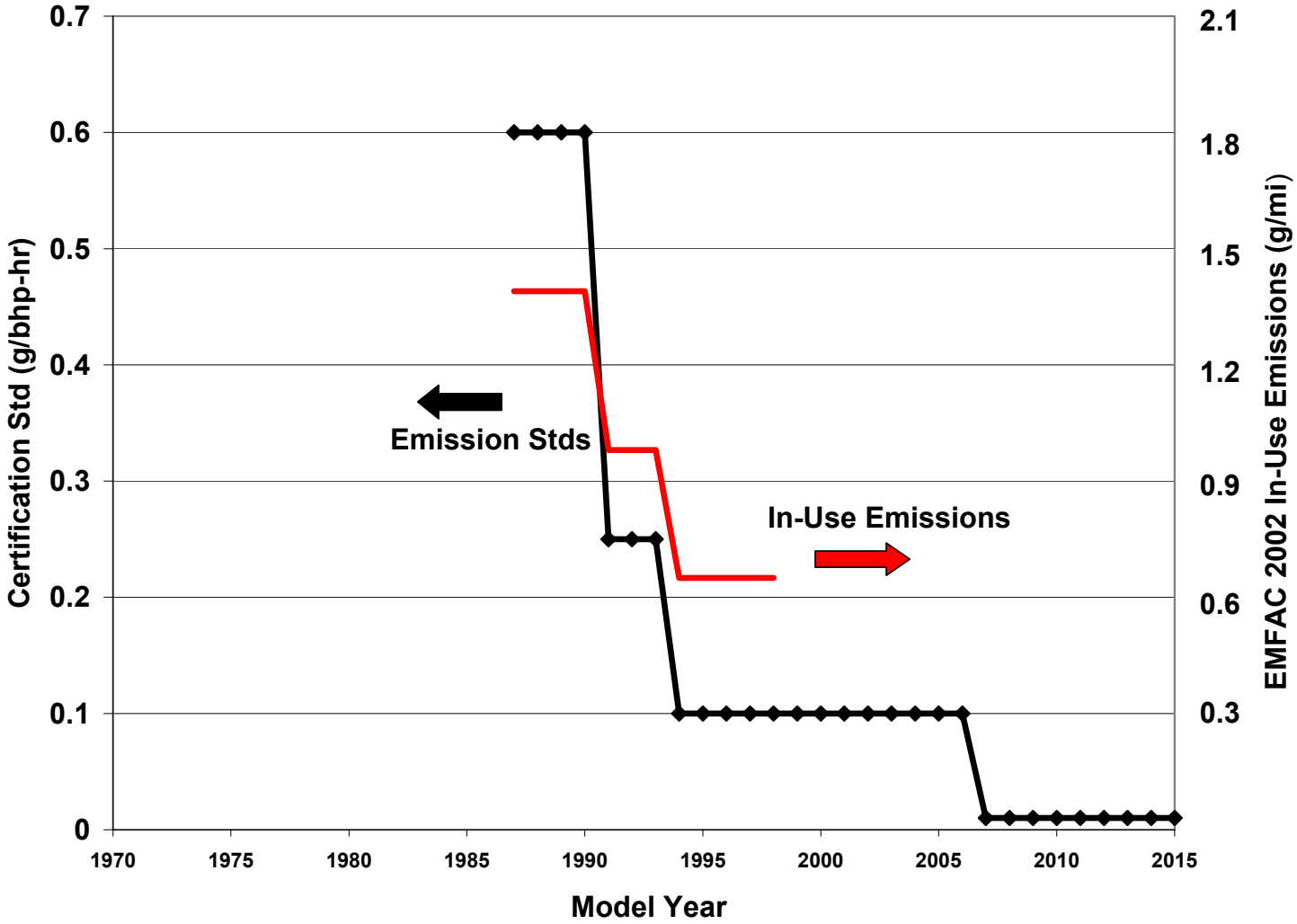


- Heavy Duty Diesel engine standards
  - NOx started in mid 1970's
  - PM started in mid 1980's
  - Standards on Diesel fuel also started in the mid 1980's (for emission control)

NOx Engine Standards and In-Use Emissions



PM Standards and In-use Emissions

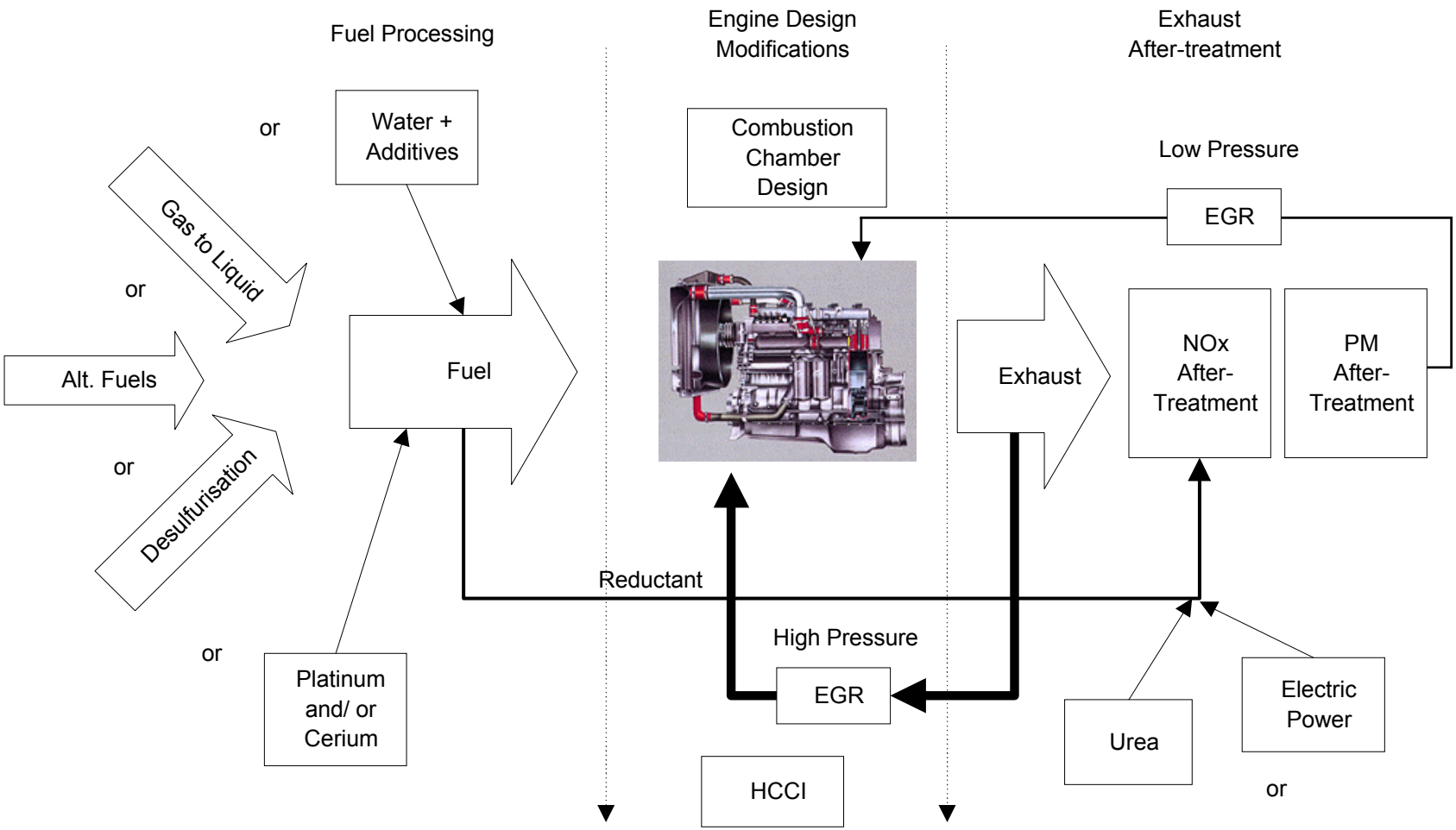


Annual Benefits of On-Road 2007/2010 Heavy-Duty Standards

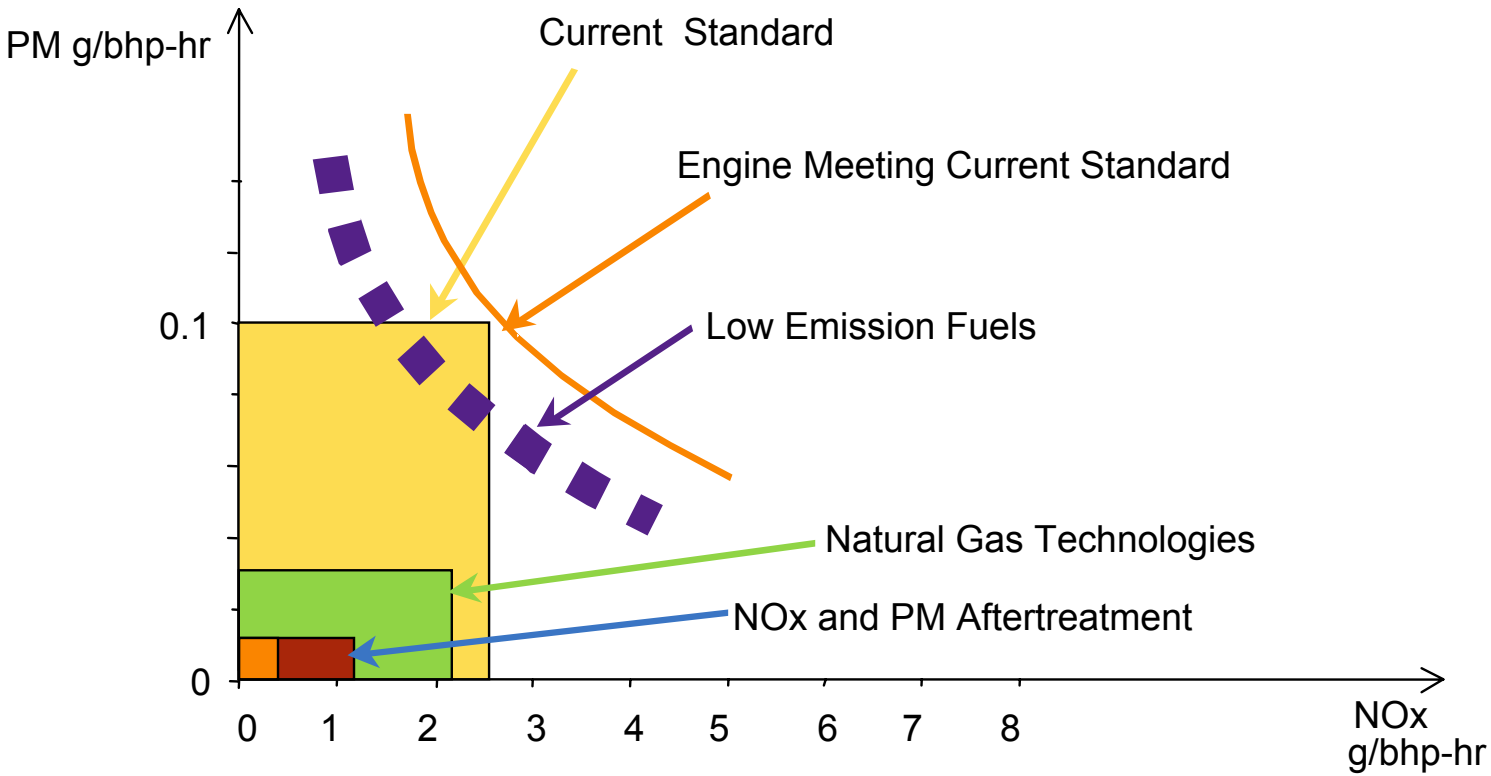
- 2.6 million tons of NOx, 110,000 tons of diesel PM, and 17,000 tons of toxic pollutants reduced
- Emission reductions decrease exposures to ozone and direct and indirect fine particulate ($PM_{2.5}$) resulting in following health benefits
- EPA estimate of avoided cases per year in 2030
  - 8,300 premature deaths
  - 5,500 chronic bronchitis
  - 9,500 hospital admissions
  - 1,539,400 lost work days
- EPA estimates the value of these avoided cases at $70 Billion in 2030

1. Background and Issues
2. Heavy-Duty On Road Standards
3. **2007-2010 Heavy-Duty Diesel Engines**
4. Summary Comments

Future emission control strategies will be much more integrated



Potential emission reductions vary depending on the chosen approach and level of integration



To protect public health, EPA promulgated new on-road engine, vehicle, and fuel standards

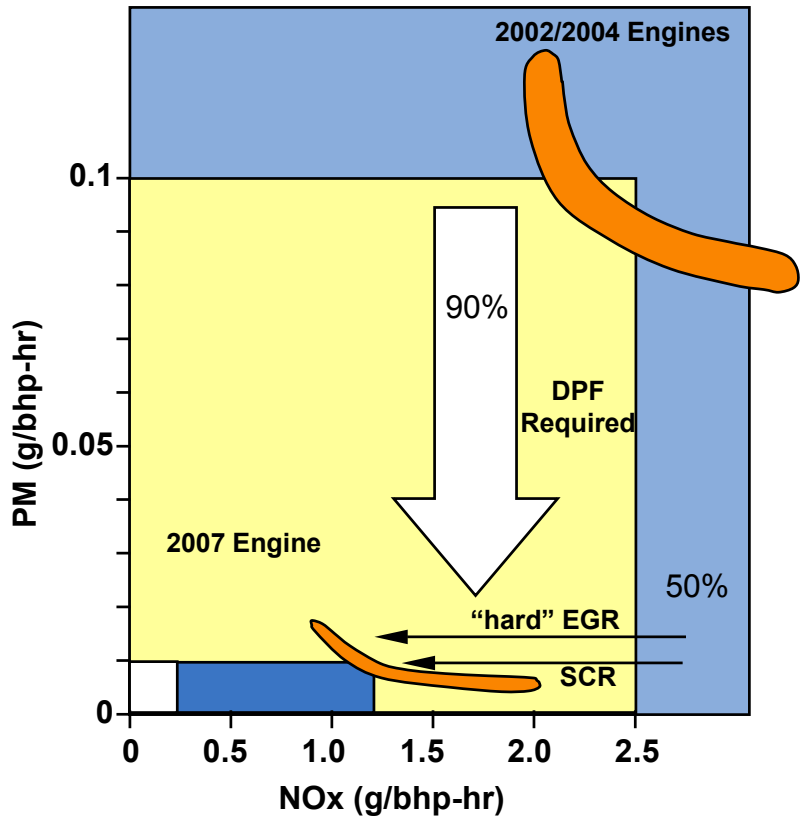
<table>
<tr><th></th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td>PM</td><td></td><td colspan="6">100% at 0.01 g/hp-hr</td></tr>
<tr><td>NOx</td><td></td><td colspan="3">50% at 0.20 g/hp-hr</td><td colspan="3">100% at 0.20 g/hp-hr</td></tr>
<tr><td>Fuel</td><td></td><td colspan="4">80% at 15 ppm maximum sulfur
(under temporary compliance option)</td><td colspan="2">100% at 15 ppm</td></tr>
</table>

Ultra Low Diesel Fuel

- Ultra low sulfur (S <15 ppm) will be required in 2006 timeframe
- Small PM reduction (15%)
- Technology enabler for DPFs and NOx aftertreatment like lean NOx catalysts or NOx adsorbers
- California also requires low aromatics to get NOx reduction in existing fleet
  - equivalent fuel formulations also acceptable
- Other diesel fuel formulations are also being introduced
  - emulsified fuels like PuriNOx
  - ethanol blends with diesel called E-Diesel
  - biodiesel either as blend or use neat

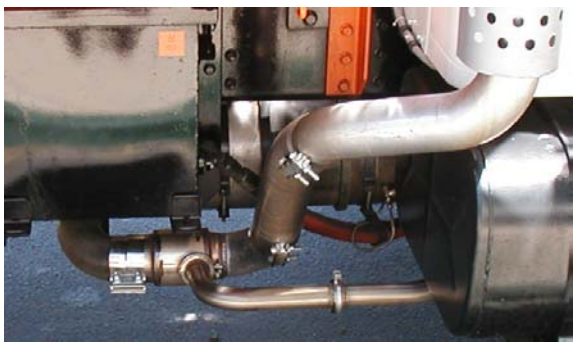
Diesel Engines Meeting 2007 Standards

- Ultra low sulfur (S <15 ppm) will be required in 2006 timeframe
- Active regeneration diesel particulate filters will be needed
- Two NOx control options were considered
  - "Hard" Exhaust Gas Recirculation (EGR)
  - Selective Catalytic Reduction (SCR) using urea as reductant
- Engine Manufacturers will predominately use EGR in 2007 engines



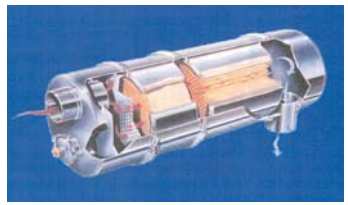
Tradeoffs of NOx control for 2007

High Pressure EGR Engine



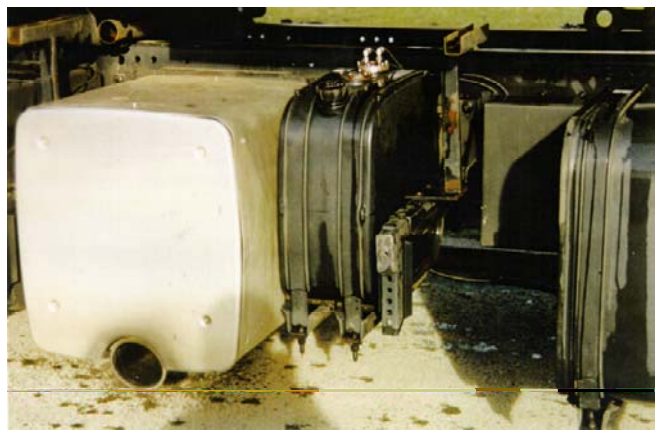
Low Pressure EGR

Diesel Particulate Filters



Johnson Matthey
CRT

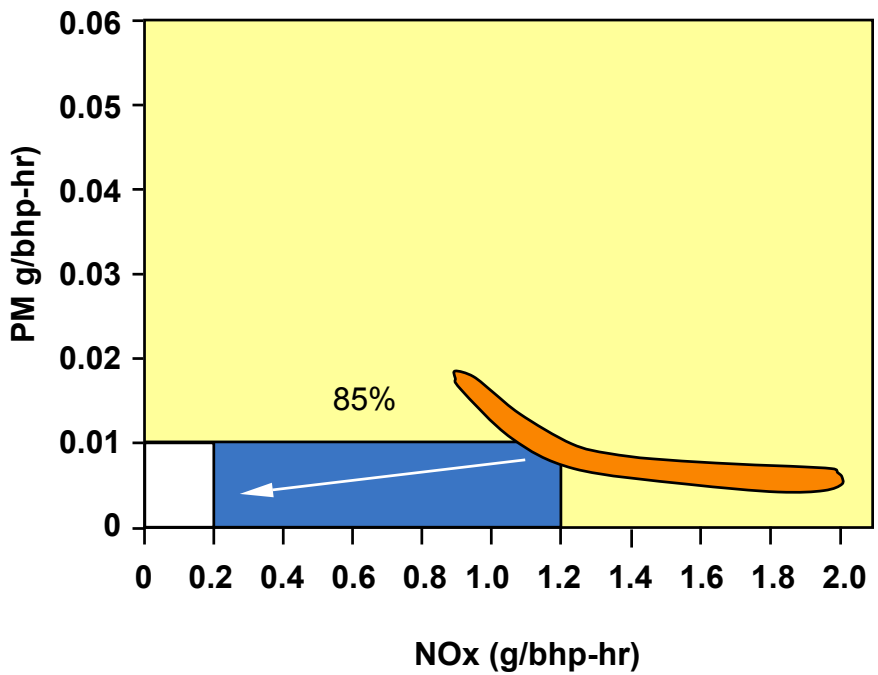
Engelhard
DPX



SCR Catalyst and Urea Storage Tank

Diesel engine meeting 2010 standards

- ULSD fuel
- Active DFP
- Integrated engine, DFP, NOx Control System
  - SCR
  - Lean NOx catalyst
  - NOx adsorbers
- HCCI with variable valve timing and integrated aftertreatment



1. Background and Issues
2. Heavy-Duty On Road Standards
3. 2007-2010 Heavy-Duty Diesel Engines
4. Summary Comments

Comparison of 2007/2010 engine technologies to diesel engine meeting 1998 standards of 4 g/bhp-hr NOx and 0.1 g/bhp-hr PM

Effects on Fuel Consumption

- Diesel Engines
  - DPF — Small reductions
  - EGR — 6 to 10% reduction
  - SCR* — 2 to 3% reduction
  - Lean NOx Catalyst, NOx Adsorber — 2 to 6% reduction
- Natural Gas Engines
  - Spark ignited LB — 20% reduction
    - Oxidation Catalyst — —
    - SCR — 2-3% reduction
  - HPDI — 0%
    - DFP — Small reduction
    - SCR — 2-3% reduction

*Assumes Urea price comparable to diesel

Effects on Costs

- Diesel Engines
  - ULSD — $0.05/gallon increase
  - Lower mpg
  - Increased first cost for integrated engine and emission controls
- Natural Gas Engines
  - No added cost of fuel
  - Lower mpg but depends on fuel cost price differences
  - Increased first costs for integrated engine and emission controls

Evaluating technologies over vehicle life will be even more important in making buying decisions

- Life cycle costs of competing technologies
  - First costs
  - Fuel costs
  - Other O&M costs
  - Infrastructure costs (if not included in fuel costs)
- Other considerations
  - Upstream emission benefits of natural gas
  - Greenhouse gas emissions benefits
  - Ground and water pollution benefits
  - Petroleum reduction benefits

Thank You For Your Attention

Contact Michael D. Jackson
jackson.michael@tiaxllc.com